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13. ABSTRACT *(Maximum 200 words)*

The diagnostic equipment purchased under this DURIP grant directly supported University of Maryland basic research under the DOD MURI on Innovative Vacuum Electronics (AFOSR subcontract 99RA073403). Specifically, we studied advanced gyro-amplifiers and phase-locked oscillators operating at harmonics of the electron cyclotron frequency. Recently, a Ka-band harmonic inverted gyrotwystron (phigtron) was studied for which 720 kW of peak power, with a bandwidth of 0.7%, saturated gain of 30 dB and efficiency of 35% was demonstrated. Phase stability, noise spectrum and nonlinear gain characteristic were investigated using the new pulsed RF signal diagnostics system purchased under this grant. The experiments not only confirmed theory, but were also in very good agreement with numerical analysis using the electro-dynamic code, MAGY. The results represent the first demonstration that "backed-off" operation improves phase stability in frequency-doubling harmonic gyro-amplifiers. The key factor for success in achieving the results has been the high dynamic range and accuracy afforded by the new diagnostic system. So far, six PhD and numerous undergraduate students have employed the system in the course of their research projects. The impact on their training has been invaluable.

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Pulsed RF Signal Diagnostic System for Gyro-Amplifiers

Final Report

For period 4/1/2001 to 4/1/2002

AFOSR DURIP Grant No. F496200110256

Submitted to

Dr. Robert J. Barker
Air Force Office of Scientific Research

By

Institute for Research in Electronics and Applied Physics
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Principal Investigator

John Rodgers

Pulsed RF Signal Diagnostic System for Gyro-Amplifiers

I. Summary of the Purpose and Impact of the DURIP Program

The University of Maryland, with support from the DOD MURI on Innovative Vacuum Electronics (AFOSR subcontract 99RA073403), conducts research on advanced gyro-amplifiers and phase-locked oscillators operating at harmonics of the electron cyclotron frequency. These devices may significantly enhance the capability of high-resolution coherent millimeter-wave radar for military applications. In addition to improving power, gain and bandwidth in this new class of amplifiers, it has become increasingly important to characterize their signal and noise properties. Theoretical studies of phase stability and noise in gyro-amplifiers have suggested that operating parameters may be chosen where, with a relatively small tradeoff in gain, substantially improved phase stability can be achieved. However, the effect had never been demonstrated experimentally. Recently, a Ka-band harmonic inverted gyrotwystron (phigtron) was studied where 720 kW of peak power, with a bandwidth of 0.7%, saturated gain of 30 dB and efficiency of 35% was demonstrated. Phase stability, noise spectrum and nonlinear gain characteristic were investigated using the new pulsed RF signal diagnostics system purchased under this contract. The experiments not only confirmed theory, but also very good agreement with numerical analysis using the electro-dynamic code, MAGY, was demonstrated. The results represent the first demonstration that "backed-off" operation improves phase stability in frequency-doubling harmonic gyro-amplifiers. Currently, studies are underway on wideband gyro-TWT amplifiers, which show promise as well. In all cases, the key factor in achieving the results has been the high dynamic range and accuracy afforded by the new system. So far, six PhD and numerous undergraduate students have employed the system in the course of their research projects. The impact on their training has been invaluable.

II. Summary of Achievements

a. Equipment purchased and delivered by 07/1/2001 (see Appendix A for final budget summary)
b. System construction completed 08/24/2001
c. System software development completed 12/31/2001
d. Calibration and acceptance testing completed 01/30/2002
e. Diagnostic system put into service and Gyro-amplifier testing began 01/21/2002
f. Relevant publications listed in Appendix B

Appendix B

1) Abstract of paper presented at IVEC 2001

A Ka-band Frequency-doubling Harmonic Gyro-TWT: Summary of Results from Studies on Phase Stability

J. Rodgers, G. S. Nusinovich, H. Guo, W. Chen and V. L. Granatstein
Institute for Plasma Research (IPR), University of Maryland, College Park, MD 20742

A millimeter wave, frequency-doubling harmonic gyro-TWT, shown in Fig. 1, is being studied experimentally and theoretically. Peak power of 200 kW at the second harmonic of the electron cyclotron frequency, centered at 33 GHz with a bandwidth of 3% and gain of 20 dB has been demonstrated [1]. It is of interest to investigate phase coherence, noise and stability in these new gyro-amplifiers and seek to determine whether conventional TWT-like performance is achievable by the fast wave counterpart. Here, we report the results of a study on phase sensitivity (stability) in the device due to fluctuations in beam voltage, guiding magnetic and other operating parameters [2]. Knowing the phase stability characteristics gives important insights into the nonlinear beam-wave interaction that produces gain at twice the injection frequency, and the system phase noise can then be predicted and addressed to a degree by specifying how well regulated the power supplies in the system should be. Phase noise from internal electronic processes is not treated in this study.

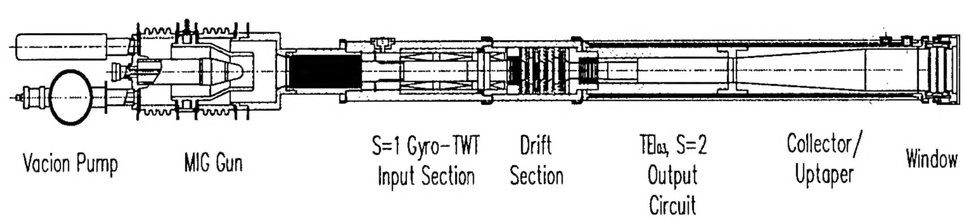


Fig. 1. 33 GHz Frequency-doubling Harmonic gyro-TWT

The experiment, shown schematically in Fig. 2(a), is performed in the following manner. An input signal is injected into a Ku-band, fundamental gyro-TWT section where it modulates a 48 kV, 30 A electron beam. After transit through a drift section, the electron beam, which becomes bunched in orbital phase, excites the TE_{03} mode in an overmoded output waveguide at twice the input frequency. The input and output phase difference is measured using a harmonic phase discriminator circuit, and the gyro-TWT operating parameters (beam voltage, current, velocity pitch ratio and interaction magnetic field) are varied around their nominal values. Changing the beam-wave interaction parameters produces variation in the amplifier phase delay, and fluctuations in those parameters contribute to phase noise. The results, shown in Fig. 2(b), illustrate the phase sensitivity to deviation in the beam voltage and external magnetic field.

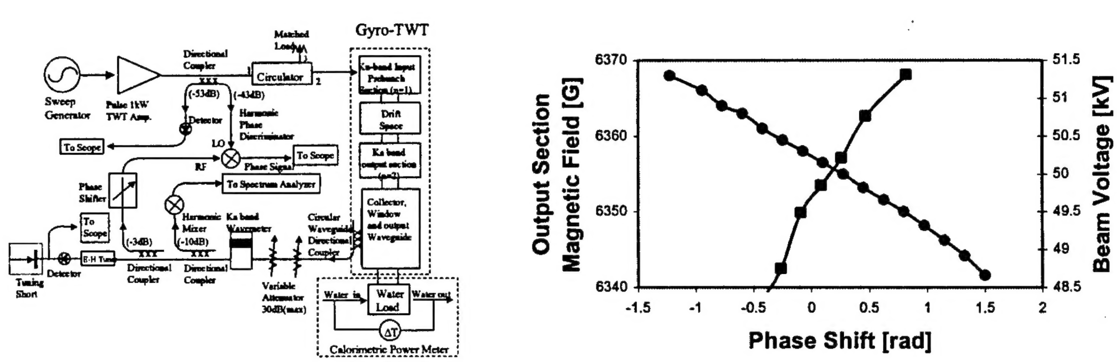
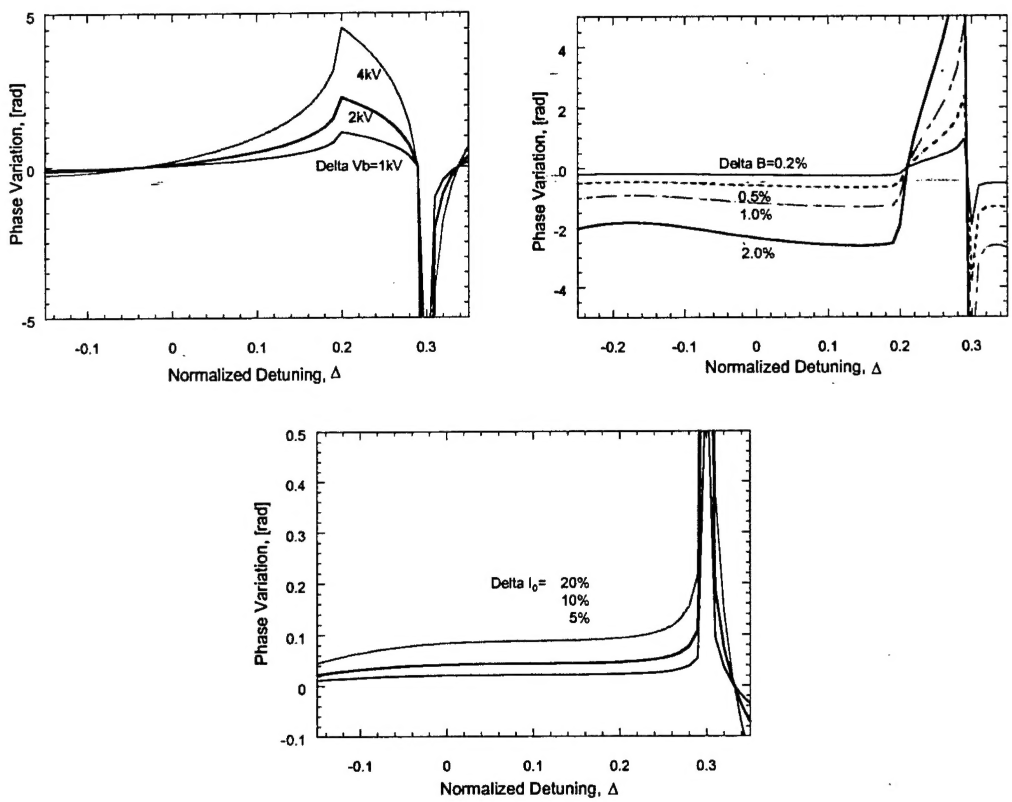


Fig. 2 (a) Schematic of Gyro-TWT Phase Stability Measurement, (b) Dependence of Phase on Beam Voltage (dots) and Magnetic Field (squares)

An analytical theory was developed to describe synchronous interactions in frequency-doubling multi-stage gyro-TWTs [2]. It was assumed that (a) the input circuit operates in the small signal regime, (b) the drift section is radiation free and (c) the output circuit can be analyzed in a specified current approximation. For the input waveguide, a set of self-consistent equations was reduced to a dispersion equation and, once the appropriate boundary conditions were applied, the wave propagation constants were derived. The partial derivatives of wave phase in the output circuit with respect to the various technical parameters were solved numerically over a range of parameters that encompassed the experimental conditions. Figure 3 (a)-(c) are plots of phase vs. voltage, operating magnetic field and electron beam current, respectively.



We will report the experimental measurement of phase pushing, an overview of the theoretical treatment and a comparison of the experimental data and numerical calculations, which are in good agreement. The results show that phase stability in a frequency-doubling harmonic gyro-TWT may be improved through the choice of operating parameters, possibly with some sacrifice in gain or efficiency. Also, good phase stability may be achieved using practical power supplies with adequate regulation.

This work is sponsored by the DOD MURI program on innovative vacuum electronics under UC Davis subcontract 99RA073403 and AFOSR contract F49620-99-1-0197.

References

1. H. Guo, V. L. Granatstein, J. Rodgers, J. J. Zhao, W. J. Chen, Y. Miao, "Progress in experimental studies of harmonic multiplying gyro-amplifiers," Presented at *IEEE Conf. Plasma Sci.,* June, 1999.
2. G. S. Nusinovich, J. Rodgers, W. Chen and V. L. Granatstein, "Phase stability in gyro-traveling wave tubes," *IEEE Trans. E.D.*

2) J. Rodgers, T. M. Antonsen, V. L. Granatstein, G. S. Nusinovich, Y. Miao, *"Improved Phase and Gain Stability in Gyro-traveling Wave Amplifiers with Detuned Cyclotron Mismatch,"* IEEE ICOPS 2002.
3) G. S. Nusinovich, O. V. Sinitsyn, J. Rodgers and V. L. Garnatstein, *"Comparison of two gyroklystron concepts: frequency multiplication versus operation at a given cyclotron harmonic,"* IVEC 2002
4) J. Rodgers, H. Guo, G. S. Nusinovich and V. L. Granatstein, "Experimental study of phase deviation and pushing in a frequency doubling, second harmonic gyro-amplifier," *IEEE Trans. E. D.,* VOL, NO. 10, October, 2001.

Appendix A

Requisition List for 5-28356, Expiration Date: 03/31/02
Expended thru: 4/30/02
Principal Investigator: John Rodgers
Funding Agency: AFOSR

Req. No.	Item	P.O. #	Purchaser/Note	Input Date	Perm, Eq. Obligated	All Others Obligated	Perm. Eq. Expended	All Others Expended	Exp. Date
16	Agilent Technologies	H104911	Rodgers	03/29/01					
	Signal Generator #83731B			10/05/01			31512.00		08/31/01
	Misc. Adapters and Sensors			10/05/01			7156.00		08/31/01
	Calibration Kit #R11644B			10/05/01			3764.00		08/31/01
	Power Meter #E4419B			10/05/01			4136.00		08/31/01
	VEE Pro v. 6.0			10/05/01			495.00		08/31/01
	Synth. Sweeper #83650L			10/05/01			42080.00		08/31/01
	Spectrum Analyzer #8564EC			10/05/01			42802.20		08/31/01
	reversing invoice entry Inventory			10/08/01				-6547.00	10/31/01
	correct above error	INV0030		04/05/02				6547.00	04/30/02
	Waveguide Adapter #R281B		74319	10/10/01			1872.00		10/31/01
17	Hart Sci	PCRD09	IPR367	11/01/01			2788.00		10/31/01
					0.00	0.00	136605.20	0.00	
					0.00	0.00	136605.20	0.00	
			Total Obligated		0.00		136605.20		
			Total Expended		136605.20				
			Total Costs		136605.20				
			Budget		136699.00				
			Balance		93.80				